ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
Procedia Engineering 2 (2010) 2407–2412
Procedia Engineering
www.elsevier.com/locate/procedia

8th Conference of the International Sports Engineering Association (ISEA)

# Lessons Learned from the Aerodynamic Shape Development Process of a Bobsleigh

Albert Pernpeintner[a], Andreas Winkler[a*]

[a]*Technische Universität München, Boltzmannstrasse 15, 85748 Garching, Germany*

Received 31 January 2010; revised 7 March 2010; accepted 21 March 2010

**Abstract**

Experiences made with the systematic aerodynamic development process of a bobsleigh are presented. The challenges and the potentials of the preliminary design phase and of the detail optimization phase are discussed. It is demonstrated that the appropriate application of the tools and methods leads to a considerable increase in the product quality. The challenges that arise from field testing under unfavourable weather conditions are addressed.



*Keywords:* bobsleigh; aerodynamics; computational fluid dynamics; shape optimization; crew position; crew posture; automation;

## 1. Introduction

As part of a multi-disciplinary project and in cooperation with small and mid-size companies and with members from the Bavarian bobsleigh community, the shape of a bobsleigh was aerodynamically optimized [1] [2] [3]. The development objective was to reduce the aerodynamic drag. While several previous works [4] [5] [6] [7] [8] focused on some bobsleigh components, this time the optimization process was applied to the bobsleigh as a whole. It was a precondition to use tools and methods that are available for small and mid-size companies. The development task was approached with the systematic development process shown in Figure 1. The different development phases were characterized by these methods and tools. At the same time, each method was subject to particular constraints.

In the preliminary design phase, computational tools were preferentially applied consisting of a CAD system and CFD simulation software. The principally limited computing capabilities necessarily led to simplifications concerning the degree of shape details, the turbulence modelling and the operating state. For detail optimization, wind tunnel tests were performed using a subscale model. The subscale model generally requires shape simplifications and simplifications of the boundary conditions dictated by the operating state. Further confinements were given by limiting factors of the wind tunnel test section. Finally, a full scale prototype shall be used for field tests that are not subject to any simplifications and hence are suited for validating the computational and experimental tools.

The cooperation with various disciplines, with small and mid-size companies and with people of varying technical background posed many challenges to the development process. This combination of influences on the aerodynamic development process can be considered to be typical for sports engineering. Furthermore the


doi:10.1016/j.proeng.2010.04.007

systematic approach shown in Figure 1 is not limited to bobsleighs but can be applied to any piece of sports equipment whose aerodynamic properties are relevant. That is why the encountered challenges and the lessons that were learned during the development process will be addressed in this paper.

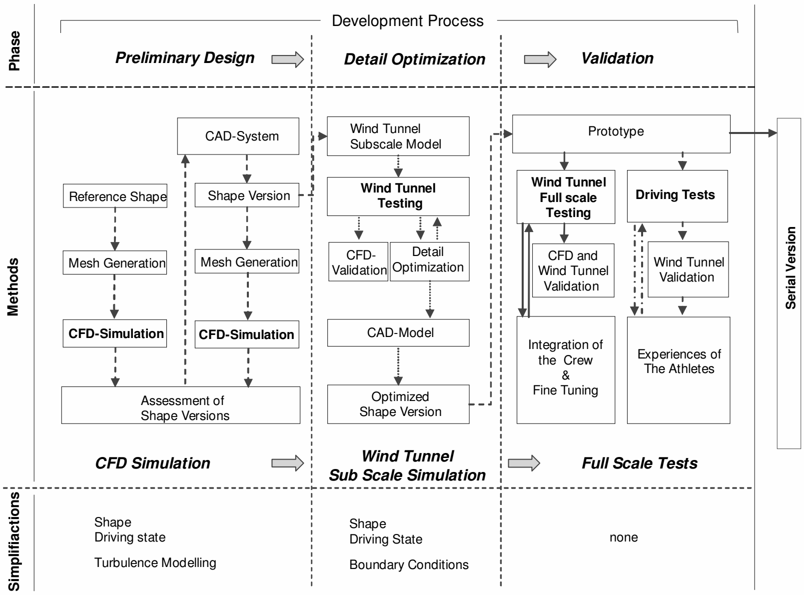


Fig. 1. Development process for the reduction of the aerodynamic drag of a bobsleigh

## 2. Preliminary Design Phase

The starting point of any development process is the definition of the development objectives. In order to find out the criteria for improving the sports equipment the athletes must also be integrated in this task. Because of the complexity of fluid mechanical effects, it is hard or even impossible for the athlete to attribute a certain behavior of the sports equipment to any flow phenomenon. That is why it is the task of the engineer to translate the articulated needs of the athlete into precise fluid mechanically relevant requirements. During the aerodynamic optimization of the bobsleigh for example it was not clear from an athlete's perspective if there is a favorable lift distribution on the front and the rear axle to improve the driving dynamics. In addition the psychological aspect adds to the difficulties of defining the development objectives appropriately. Concerning e.g. the shark skin swimsuit, Krieger [9] quotes a top-level swimmer: "... I like the way it feels. ... The suit supposedly makes you swim faster, so [when] you're wearing them - you swim faster." It is obvious that the task of defining the requirements for a fluid mechanical development process in sports engineering is challenging.

The close cooperation with the athletes is not only important for the definition of the development task. It also enhances the efficiency of the entire development process considerably if there is a steady, reliable and proficient feedback from the athlete concerning the ideas of the engineer. In this context it can be much more productive to work with athletes that are not necessarily top-level performers but who have a proficient technical comprehension. Since changes to the product become more and more expensive with advancing project status, it is very important to assure the communication with appropriate athletes in the preliminary design phase already.

In order to optimize a piece of sports equipment it is necessary to have reference values of the aerodynamic properties. Because the preliminary design phase is based on CFD simulations, these reference values must also be gained from numerical simulations. Even if experimentally gained values are available, they can hardly be used as reference for the CFD simulations due to any simplifications that are shown in Figure 1.

The digital shape file is the starting point of the mesh generation process which is shown in Figure 2. All following steps include user interactions with the software and depend on the quality of the shape file. In this context a sufficient quality means the watertight representation of the shape. Any geometric flaws lead to more or less time consuming user interactions. In case of the bobsleigh, there were initially no CAD files of the reference shape available. Hence an existing bobsleigh shape had to be digitized. The shape digitalization of the reference bobsleigh could not provide a watertight digital bobsleigh shape. Consequently a lot of manpower was consumed to create an appropriate reference shape model.

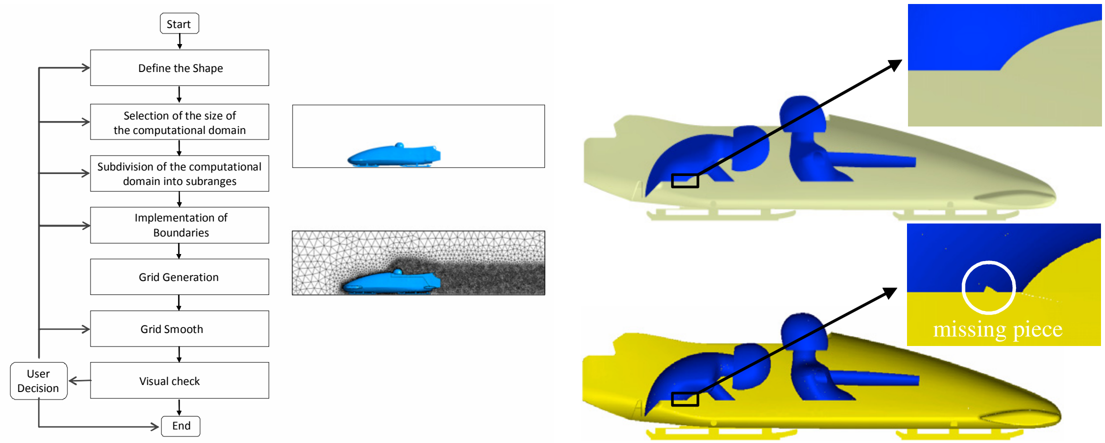


Fig. 2. (a) Process of generating an unstructured mesh around the bobsleigh, (b) Geometric flaw through file transfer from CAD (top) to the mesh generator (bottom)

Another challenge in context with the mesh generation process is the issue of file formats. An example is illustrated in Figure 3. It shows the very same shape version of the bobsleigh and the crew in the STEP file format, once created by the CAD software and once imported into the mesh generation software. On the top, the shape within the CAD software is flawless. On the bottom, after importing the file into the mesh generator, a tiny surface piece is missing. This flaw caused the whole mesh generation process to fail.

Once the reference shape was created and its aerodynamic properties were determined, the computer based optimization loop started. It was based on a parametric 3D-CAD-Modell of a bobsleigh. In addition, the bobsleigh crew was simplified by a crew representation that is shown in Figure 4. It consisted of the pilot's helmet, a horizontal plane and a plane that was inclined by the angle $\theta$. With it different brakeman postures could be simulated. In addition, several small shape details were neglected. The unstructured meshes consisted of about 3 to 4 Mio. elements, the boundary layers were resolved with ten elements normal to the wall and the SST turbulence model by Menter [10] was used including wall functions. With this set up, over 100 shape versions could be assessed.

The result of the preliminary design phase is shown in Figure 5. The optimized shape version (InnoBob) shows a drag decrease of about 13% compared to the reference shape (RefBob). Next to this, the computational tools provides further advantages to the development process.

The CFD simulation inherently generates information about the flow field in the entire domain around the bobsleigh [1]. This information enhanced the understanding of the aerodynamic properties of the bobsleigh significantly. For example the contributions of the various bobsleigh components to the total drag could easily be determined, as is shown in Figure 5. The same amount of information is not achievable with wind tunnel tests for this number of shape versions. In addition, the computational tools allow for the complete automation of the development loop [2] which increases the development efficiency distinctively.

To sum up, it is very important to realize that the shape generation and in particular the digitalization of a given surface for the use in CFD simulations is complex and can become very time consuming. The same is true for the file format handling. In this context it is important to agree on an appropriate file format with other disciplines at the very beginning of the development project. On the other hand, a parametric 3D-CAD model, possibly including appropriate shape simplifications, and the assessment of various shape versions by CFD simulations are powerful tools in the preliminary design phase.

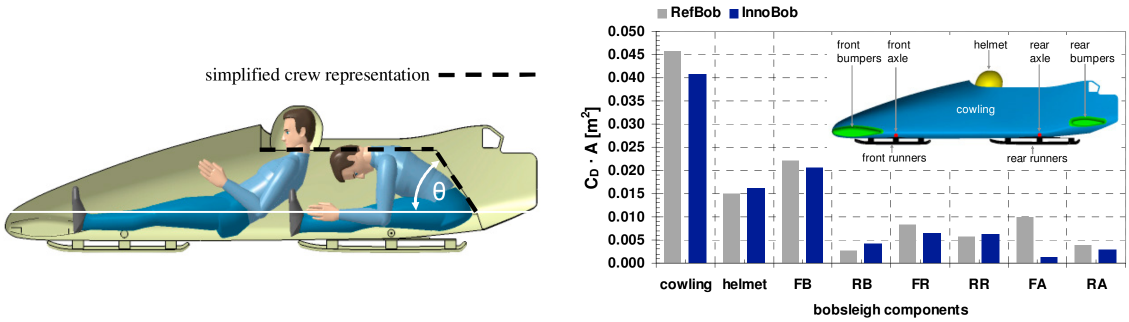


Fig. 3. (a) Simplified representation of a bobsleigh crew, (b) Result of the preliminary design phase of the bobsleigh

## 3. Detail Optimization Phase

The next step in the development process was the detail optimization with a subscale model in the wind tunnel. The main advantages of the wind tunnel tests are the efficient measurements of integral flow variables like the aerodynamic force coefficients and the full coverage of the flow turbulence. Therefore wind tunnel tests are also an important tool for validating the CFD simulations. In addition unsteady flow phenomena can possibly be investigated more efficiently in the wind tunnel than in CFD simulations.

For the detail optimization of the bobsleigh a modular 1:3 subscale model was built. It was made of PU foam which allowed efficient changes of shape details. It contained the same simplifications for representing the crew like the CAD-model of the preliminary design phase. Using the wind tunnel model several bobsleigh components could be optimized and significant properties of the flow field could be revealed.

The components that could be optimized in the wind tunnel comprised the diffuser and the overall geometry of the brakeman access on the rear side [1]. Moreover the wind tunnel tests also revealed some remarkable characteristics of the flow field that pointed at further drag decrease potential.

In Figure 6 the dependence of the drag coefficient on the brakeman's back angle θ is shown. It is apparent that the drag decreases with increasing back angle. In Figure 7 the corresponding flow pattern near the cowling edge is shown for the back angles of $\theta = 27°$ and $\theta = 55°$. The flow directions were visualized by a pattern of filaments that were distributed over one side of the bobsleigh cowling. These filaments showed the direction of the local flow velocity vector. The angles of the local flow velocities are defined relative to the horizontal dashed line. It becomes obvious that the angles of the local velocity vectors decrease with increasing back angle. From this follows that the mass flow over the cowling leading edge decreases with increasing back angle. From numerical simulations of the flow field [1] it was known that there are wing-tip vortices evolving from the cowling leading edge. The composition of all of these findings led to the conclusion that there is a significant drag decrease potential in the optimized positioning of the brakeman.

The relative motion between the bobsleigh and the ice track corresponds to a moving solid boundary. In order to simulate the natural operating conditions as good as possible a wind tunnel test section with a moving floor would have to be used. However, most of the wind tunnels do not posses a moving floor. Thus a systematic error is included in the wind tunnel measurements. CFD simulations showed that the effect of omitting the moving floor did not affect the aerodynamic drag significantly.

Another constraint of wind tunnel measurements is the limitation of operating conditions that can be simulated. In this study, the run through a representative curve section and through a representative straight section [1] was simulated only.

There were further simplifications that originated from the material and the manufacturing process of the subscale model. The material needed to assure that shape changes were readily possible. With the existing manufacturing process for subscale models several shape details were neglected. In addition, global shape changes that required the modification of the bobsleigh's main dimensions were in principal not possible.

For each subscale wind tunnel test, the model scale is another issue that must be addressed at the very beginning. A trade-off has to be made between the requirements "as large as possible" and "as small as necessary". A large scale is important in order to assure a sufficient Reynolds number and a sufficient size of shape details that must be resolved. The wind tunnel balance also requires a certain model size in order to guarantee the desired resolution. On the other hand, the model costs, the blockage and the length of the wind tunnel test section dictate the maximum size of the subscale model.

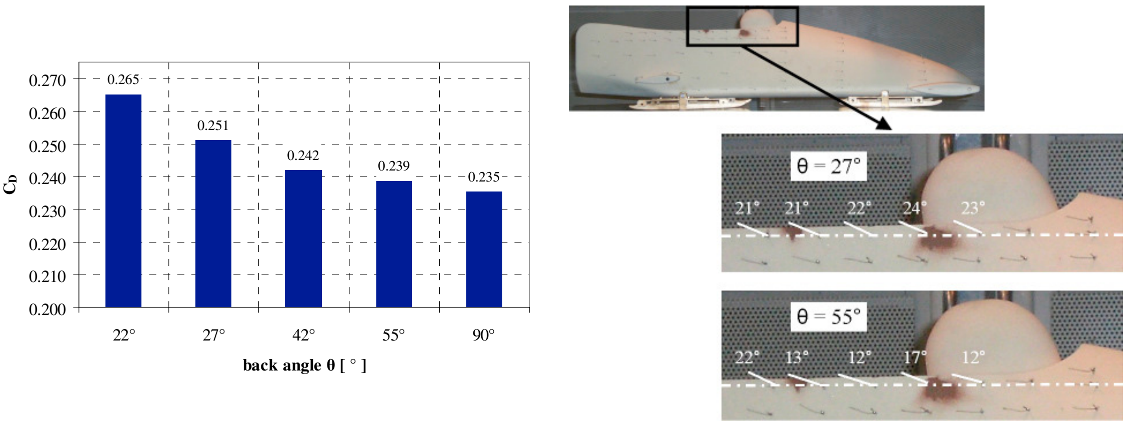


Fig. 4. (a) Effect of the back angle on the drag at $Re_\infty = 6{,}62 \cdot 10^5$, (b) Flow directions near the cowling edge at $Re_\infty = 6{,}62 \cdot 10^5$

In summary, wind tunnel tests with an appropriate subscale model are very useful in order to perform the optimization of shape details and in order to validate the CFD simulations of the preliminary design phase. The measurement of the aerodynamic force coefficients is very timesaving and is a particular strength of wind tunnel tests. In combination with the results of the numerical simulations, the findings from the wind tunnel tests can lead to a sound knowledge of the flowfield. For example, the important role of the delta-wing vortices evolving from the cowling leading edge could be pointed out and further drag decrease potential could be deduced. Care must be taken of the available boundary conditions of the test section and the scale and the material of the wind tunnel model.

## 4. Fine Tuning and Validation Phase

The final phase of the development process is based on a prototype which is used to perform full scale wind tunnel tests and field tests. The advantage of field tests is that there are no more simplifications necessary. However, it is very difficult or even impossible to measure the aerodynamic force coefficients directly. In addition the environmental conditions of the real case can be very challenging to the aerodynamic measurement instrumentation.

It is not possible to separate the different forces by measurement because the friction between the runners and the ice track cannot be directly measured either. That means that the lap time is the only measureable variable that is directly linked to the drag and friction forces. However, the lap time also depends on the driving skills of the pilot. That is why the aerodynamic forces on the full-scale bobsleigh can be finally determined in the wind tunnel only.

The vibrations of a bobsleigh during a run and the foul weather conditions pose high requirements to the aerodynamic measurement devices. First driving tests were performed using a bobsleigh with pressure tapping points. It became obvious that ice, snow and water possibly choke the small pressure bores. However, the tests did not yield any useful measurement data and require further tests.

## 5. Summary

The lessons learned from the systematic aerodynamic development process of a bobsleigh were presented. Each development phase comprised different tools and methods that were subject to particular simplifications and constraints. In the preliminary design phase, the shape generation was a crucial part where time consuming challenges had to be overcome. In principal, the CFD simulations require the modeling the flow turbulence. That inherently leads to results that deviate from the real case. On the other hand, the proper combination of computational tools resulted in the efficient assessment of over 100 bobsleigh shape versions. Thereby simplifications of the shape may be applied in order to increase the development efficiency unless these simplifications suppress any phenomena that rule the flow field.

The detail optimization was performed with a subscale wind tunnel model which allowed for easy shape changes. Moreover, the wind tunnel tests revealed further drag decrease potentials and thus lead to an iteration loop between CFD simulation and further subscale wind tunnel tests.

Driving tests with a bobsleigh entail the problem of separating the pure aerodynamic effects from other effects influencing the bobsleigh performance. In addition, the environmental conditions like icing pose harsh requirements on the aerodynamic measurement devices.

In summary, it was shown that a systematic aerodynamic development may successfully be performed using commercially available tools and methods in the preliminary design and optimization phase.

## References


[1] Winkler A., Pernpeintner A.: The Engineering of Sport 7, Vol.2. In Estivalet M., Brisson P. (Eds.) Improving the Performance of a Bobsleighby Aerodynamic Optimization. Biarritz, 2-6 June. Springer-Verlag France, 2008.

[2] Winkler A., Pernpeintner A.: Automation of the Aerodynamic shape optimization of a Bobsleigh using computational tools. In: Alam, F. et al. (ed.): Proceedings of the 4th Asia Pacific Congress on Sports Technology (APCST), Honolulu, USA, 21-23 September 2009.

[3] Pernpeintner A., Winkler; A.: Potentials and challenges for the aerodynamic shape development process in sports engineering. In: Proceedings of the 4th Asia Pacific Congress on Sports Technology (APCST), Honolulu, USA, 21-23 September 2009. Hrsg.: Alam, F. et al., RMIT University, Melbourne, 2009.

[4] Motallebi F., Dabnichki P. and Luck D.: Advanced bobsleigh design. Part 2: aerodynamic modifcations to a two-man bobsleigh. Proc. Instn Mech. Engrs Vol. 218 Part L: J. Materials: Design and Applications, 2004.

[5] Dabnichki P., Avital E.: Influence of the postion of crew members on aerodynamics performance of two-man bobsleigh. Journal of Biomechanics 39,pp. 2733–2742, 2006.

[6] Heckelmann I. Windkanaluntersuchungen zur Optimierung des Luftwiderstands eines Sportbobs. Term Paper, Lehrstuhl für Fluidmechanik, TU München, 2001.

[7] Lewis O. Aerodynamic analysis of a 2-man bobsleigh. Master of Science Thesis, Faculty of Aerospace Engineering, TU Delft, October 2006.

[8] Togneri M. Computational fluid dynamic (CFD) modelling of the flow around a bobsled. Diploma Thesis, Lehrstuhl für Aerodynamik, TU München, 2006.

[9] Krieger K. (2004) Do Pool Sharks Swim Faster? Science, Vol. 305, no 5684, 636-637.

[10] Menter F.: Improved Two-Equation k-omega Turbulence Models for Aerodynamic Flows. NASA Technical Memorandum 103975.